Hydraulic Fracturing in Underground Sources of Drinking Water at Pavillion, WY

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Photograph overlooking Pavillion Field

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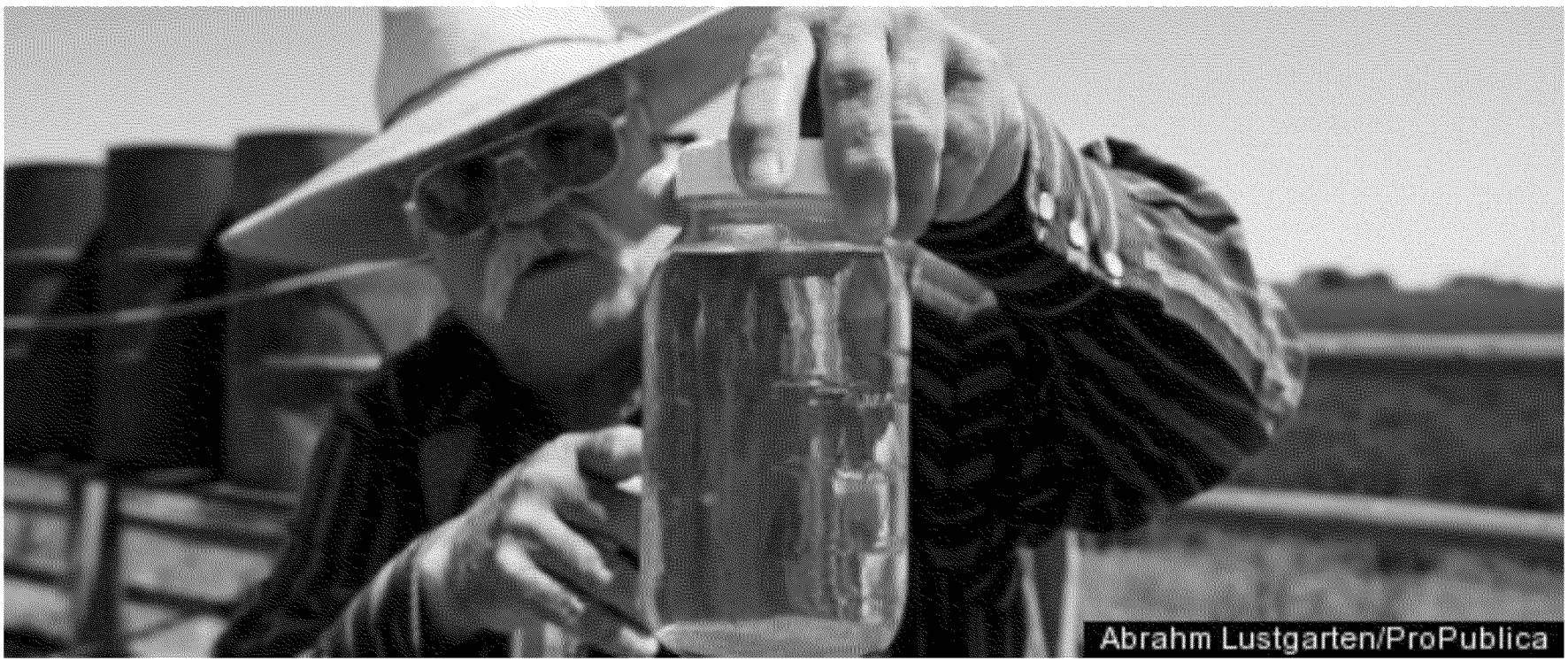
Discussion on Potential Impact to Ground Water

- Ongoing debate over the impact of well stimulation, especially hydraulic fracturing, on ground water at Pavillion and elsewhere.
- Missing from this debate is recognition that stimulation fluids have been injected directly into underground sources of drinking water with potential associated ground water resource impact.



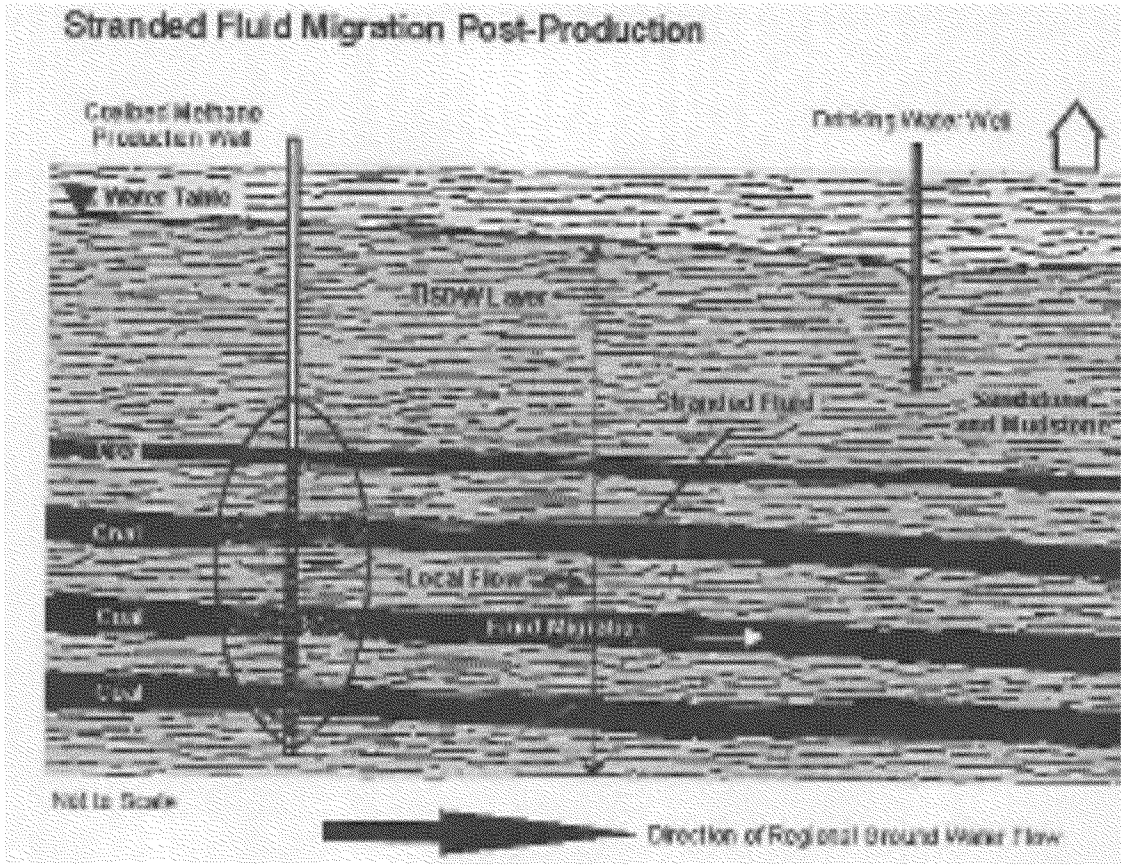
Photograph of landowner holding jar of water from his domestic well at the Pavillion Field

Ground Water and Domestic Well Impact are not Synonymous Terms

There are two related but fundamentally different questions regarding ground water contamination.

1. Has contamination of ground water resources occurred? This includes depths and formations not currently used for water supply - a ground water resource.

2. Has contamination of domestic wells occurred?



Source: EPA (2004)

A domestic well investigation is not a ground water investigation.

Definition of a USDW

Underground Source of Drinking Water (USDW) is defined in 40 C.F.R. 144.3 as a formation that currently or could supply drinking water, contains less than 10,000 mg/l total dissolved solids and is not an exempted aquifer.

The Energy Policy Act of 2005 excluded *"underground injection of fluids or propping agents (other than diesel fuel) pursuant to hydraulic fracturing operations"* from the term *"underground injection"* in the Safe Drinking Water Act.

- Injection of stimulation fluids directly into USDWs, regardless of volume and composition (with exception of diesel fuel) is not considered injection under federal regulations.
- Is "no injection" equivalent to no impact?

Hydraulic fracturing in USDWs associated with CBM Production

Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs

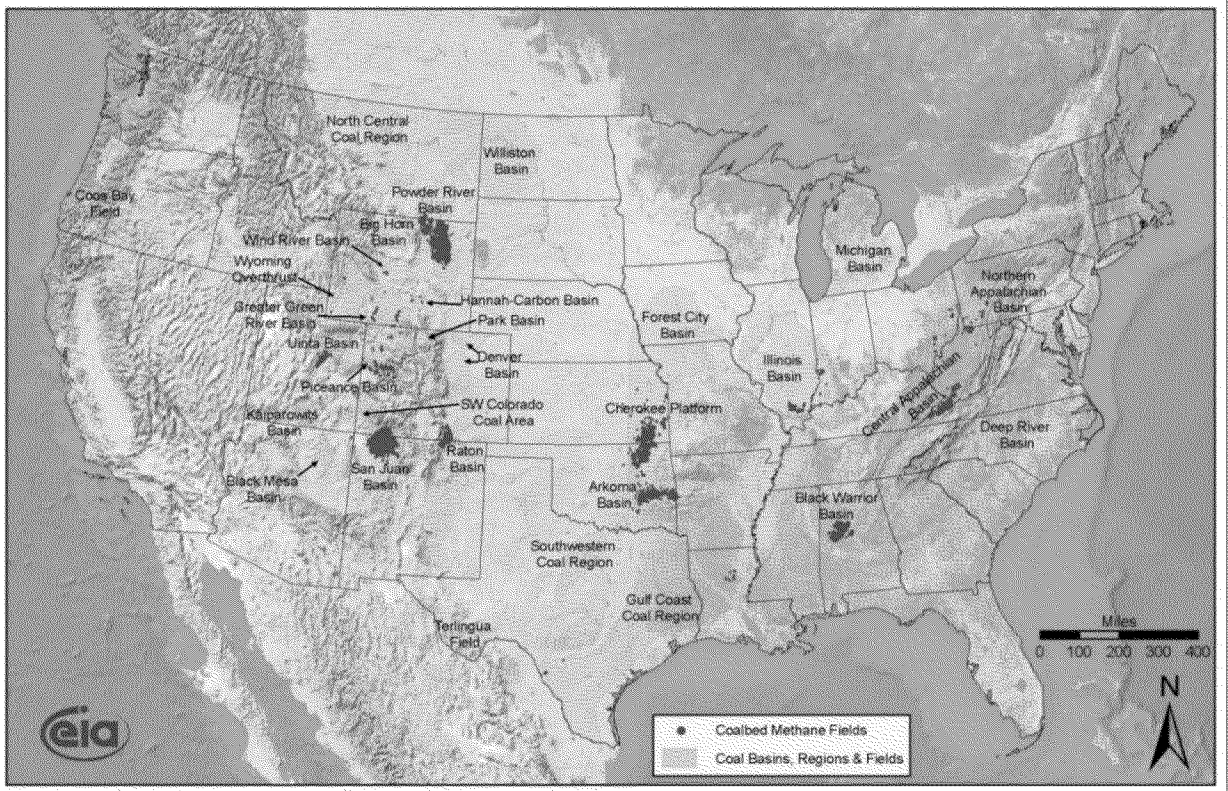
Final

"In many CBM-producing regions, the target coalbeds occur within USDWs, and the fracturing process injects 'stimulation' fluids directly into the USDWs." (EPA 2004).

In 2010, 9% of natural gas supply came from CBM (EIA 2012).

Basin	Has hydraulic fracturing occurred in USDWs?
San Juan	yes
Black Warrior	yes
Piceance	unlikely
Uinta	likely
Powder River	Infrequently
Central Appalachian	likely
Northern Appalachian	yes
Arkoma	no
Cherokee	yes
Forest City	unlikely
Raton	yes
Sand Wash	yes
Pacific Coal Region	yes

Coalbed Methane Fields, Lower 48 States

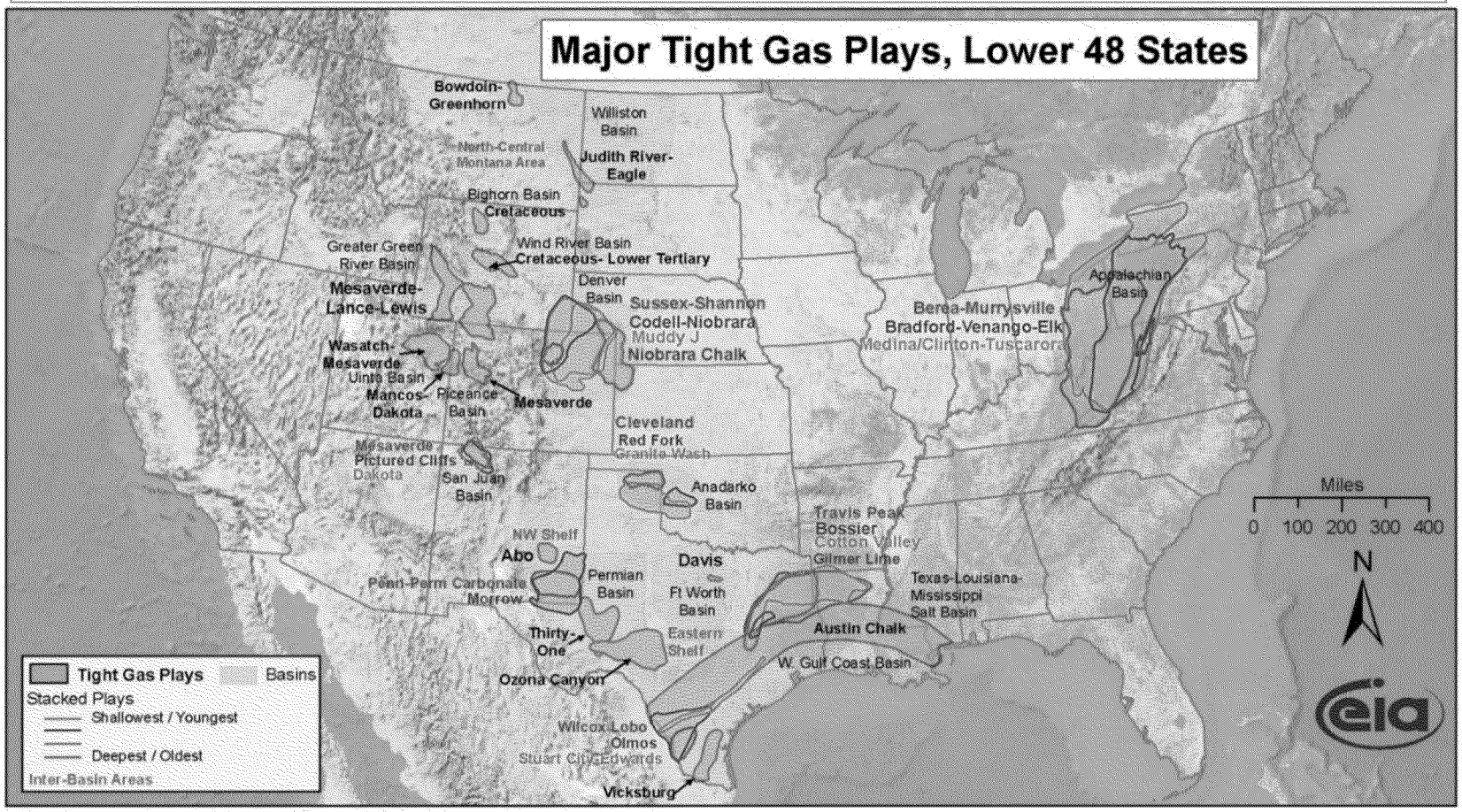


Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

Tight Gas Plays

In 2010, 26% of natural gas production came from tight gas plays (EIA 2012). Extraction from tight gas plays expected to increase 73% from 2012 to 2040 with share of total gas extraction remaining constant (EIA 2014).

Are stimulation fluids being injected directly into USDWs in tight gas plays? If so, what is the extent?



Source: Energy Information Administration based on data from various published studies
Updated: June 6, 2010

What We are Doing and Why

Research Objective

Document extent of stimulation and evaluate potential resource damage if present in USDWs in Pavillion Field.

Why do this work?

- The Pavillion Field is a tight gas play. Stimulation into a USDWs in a tight gas play has not been documented at any location.
- The extent of stimulation (number of events, depths, fluids, etc.) into a USDW has not documented in detail at any well field including at CBM locations in 2004 EPA report.
- Potential impact of direct injection into USDW has not evaluated at any specific well field including CBM locations in 2004 EPA report.

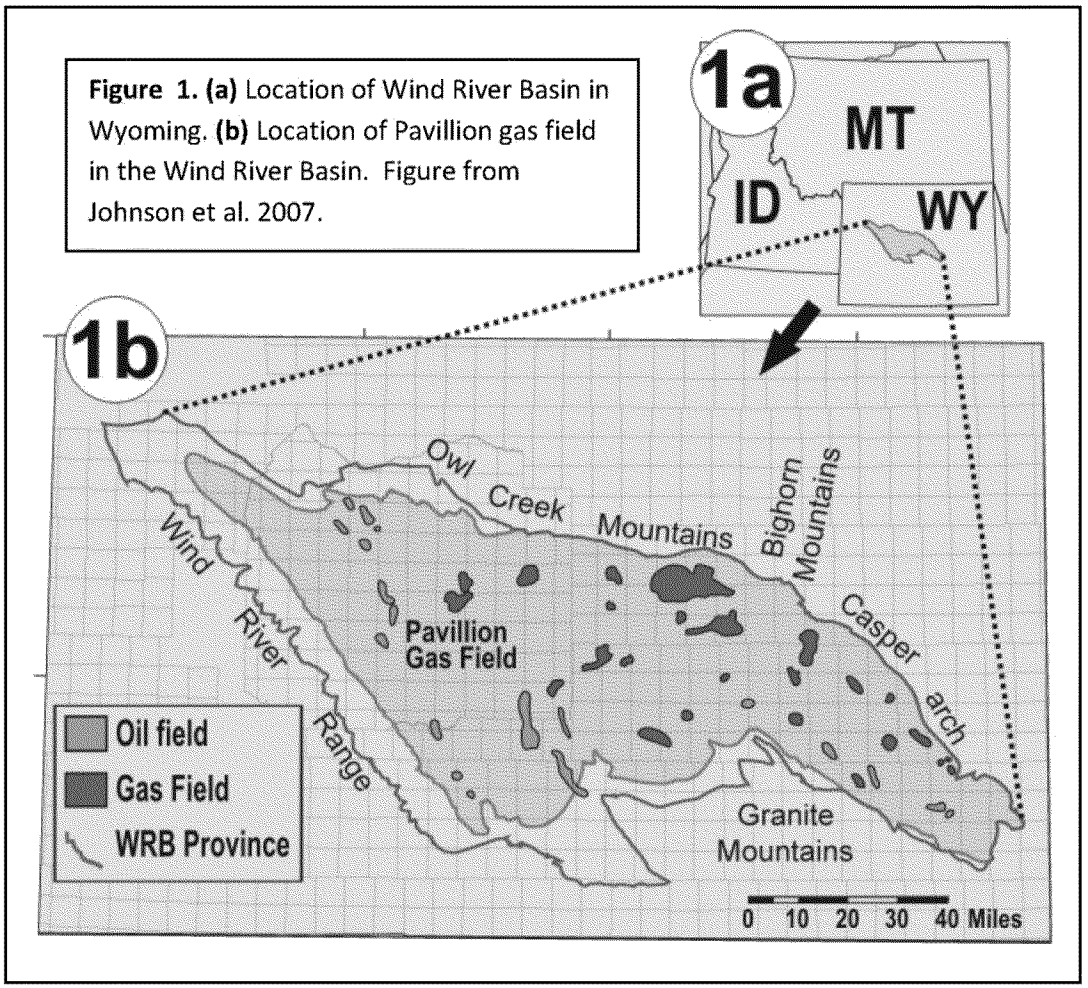
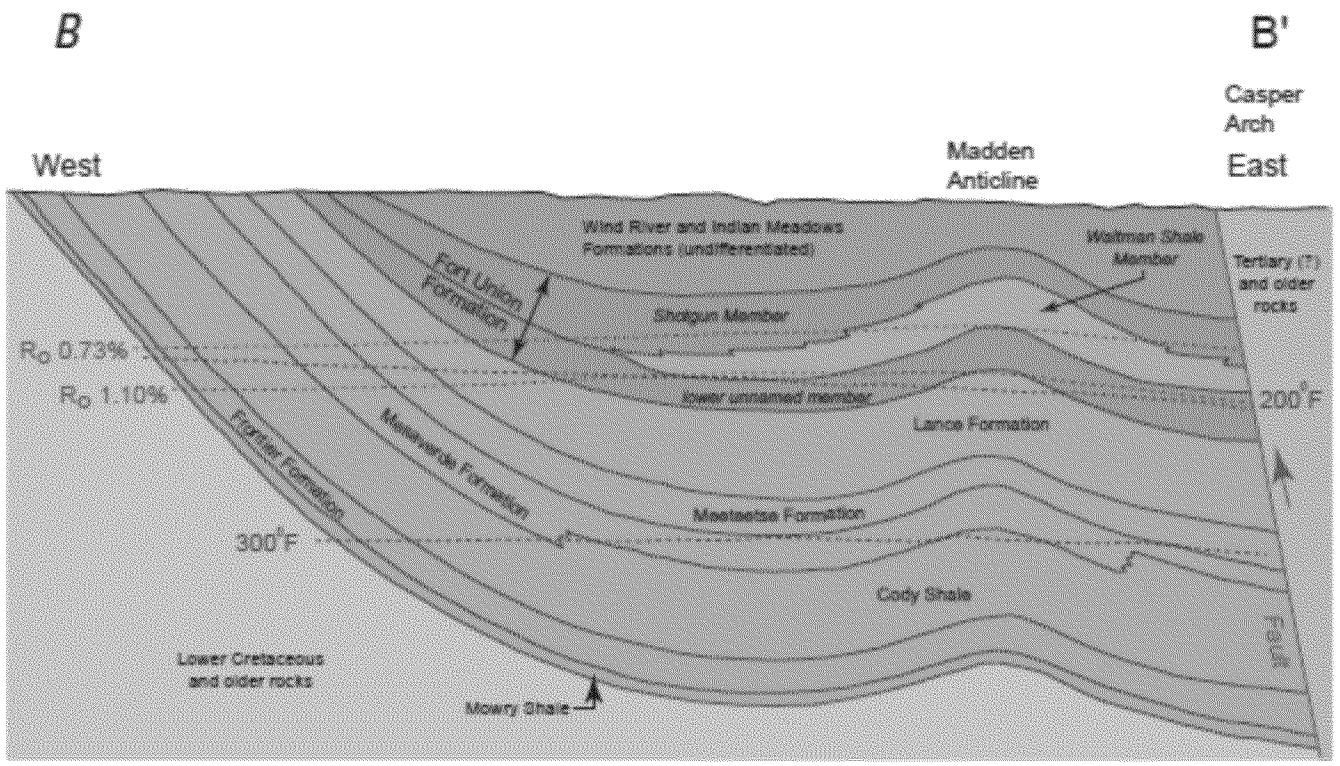


Figure 1. (a) Location of Wind River Basin in Wyoming. **(b)** Location of Pavillion gas field in the Wind River Basin. Figure from Johnson et al. 2007.

Note: The focus of the draft 2011 EPA report (DiGiulio et al. 2011) was to evaluate potential upward migration from intervals of stimulation – not impact in intervals of stimulation.

Wind River and Fort Union Formations

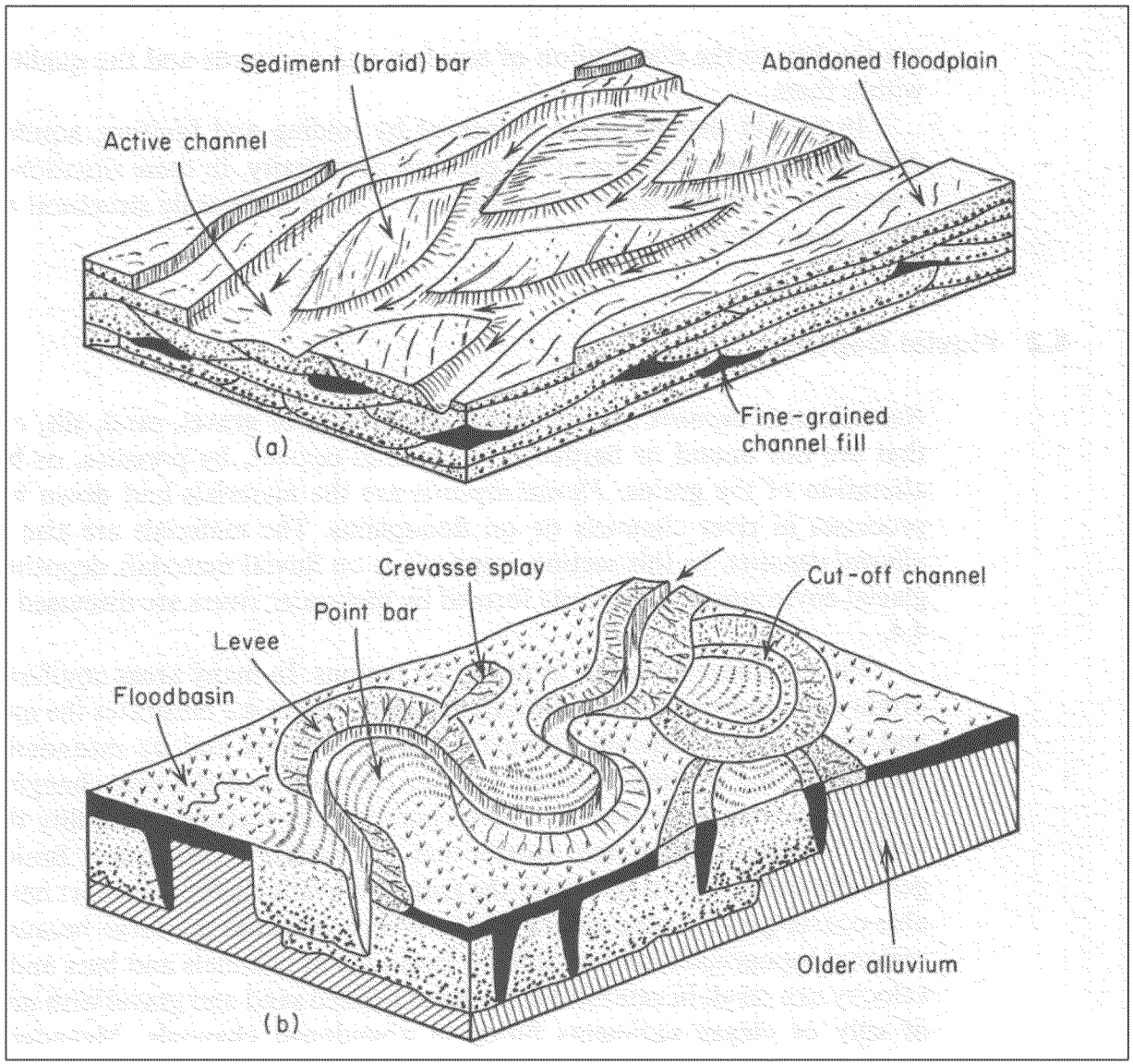


Source: Roberts et al. 2007

- Stimulation fluids were injected into the Wind River and underlying Fort Union Formations.
- Cretaceous age source rocks

Fluvial Geomorphology

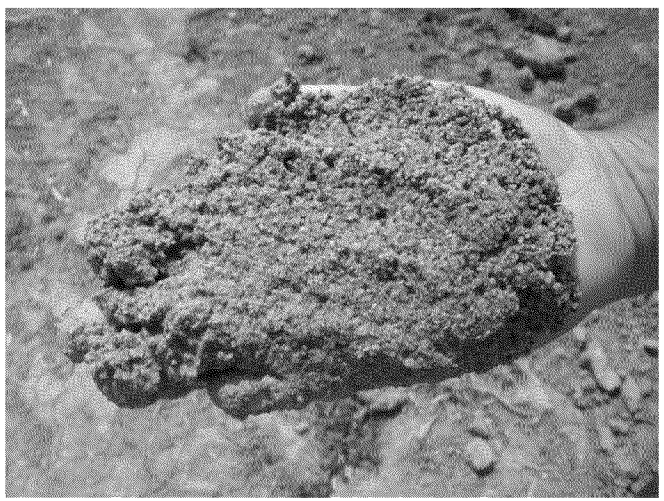
- Not monolithic sandstone units of low permeability
- Heterogeneous fluvial depositional systems. Contains connected, poorly connected, and unconnected water bearing sandstone units (McGreevy 1969). Units may be connected by fracture systems (Morris et al. 1959).
- These units surrounded by discontinuous low permeability sandstone, mudstone, and shale units.
- No extensive areal confining units.



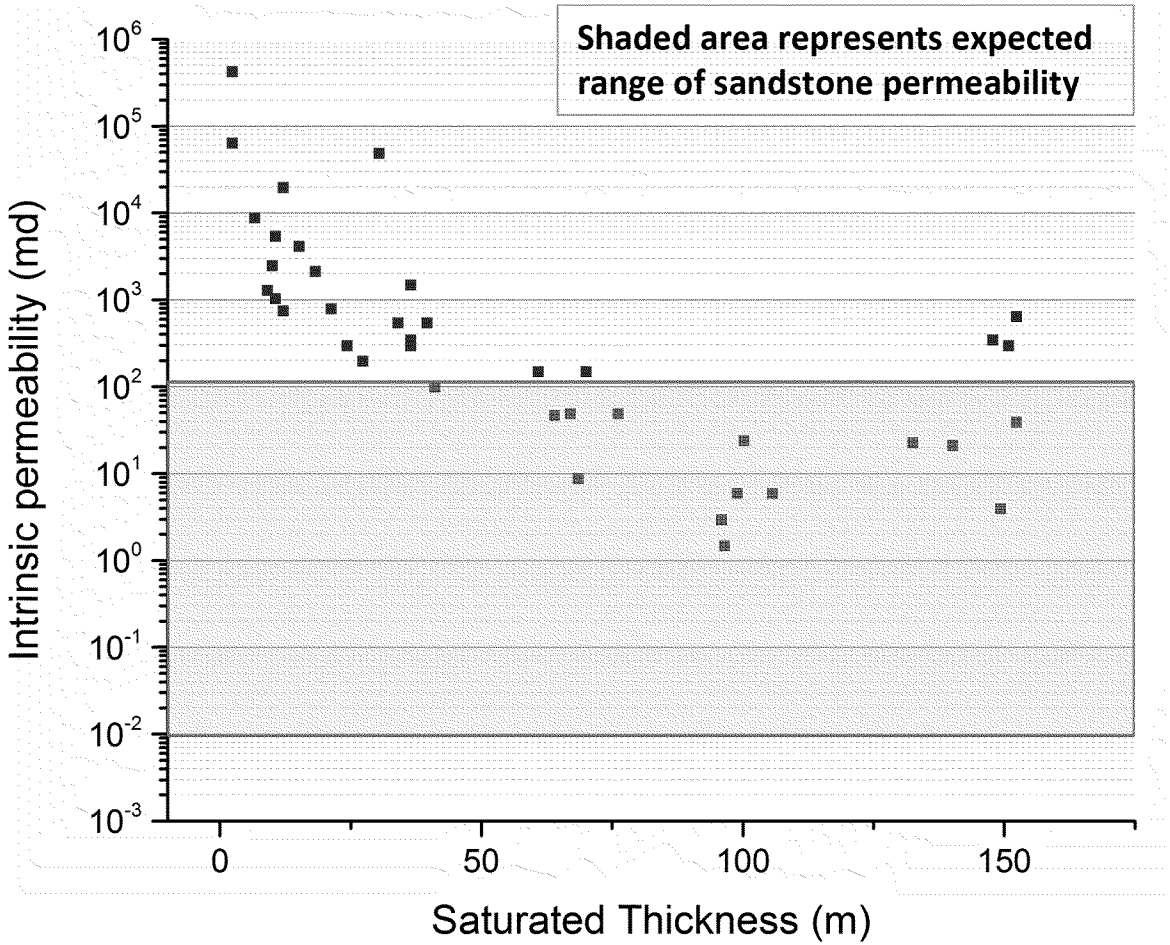
Source: Freeze and Cherry (1979)

Presence of Permeable Water Bearing Zones in Wind River Formation

White coarse-grained sandstone targeted by local water well drillers and often referred to as “water sands” in Morris et al. (1959) present in Pavillion Field



Source: DiGiulio et al. (2011)



Source: Data from Wyoming Water Development Office State of Wyoming Water Plan. Calculated from “permeability” (gpd/ft^2) using dynamic viscosity = 1.002E-02 g cm^{-1} s^{-1} and density = 1.0 g cm^{-3}

Attainment of USDW Criteria- Current Use of Wind River Formation, Potential Use of Fort Union Formation

Wind River Formation

- 5 municipal wells in Town of Pavillion supply 20,000 gpd and 7.3 million gallons per year (James Gores & Associates 2011)
- Supplies drinking water for domestic wells in Pavillion area (James Gores & Associates 2011)
- Major source of drinking water for the City of Riverton, WY (over 493 million gallons of water gallons extracted from 11 wells in 1965) (Whitcomb and Lowry 1968).
- Water yields ranging between 0.1 to 3,000 gpm and artesian zones with sufficient head to produce 200 gpm (WWDO 2003).
- Major source of drinking water throughout the Wind River Basin (Daddow 1996).
- The largest number of documented domestic well completions in Fremont County (Plafcan et al. 1995).

Fort Union Formation

- Total dissolved solids range from about 1,000 to 5,000 ppm (McGreevy et al. 1969).
- Wind River and Fort Union Formations defined as aquifers by Wyoming Water Development Office (WWDO 2003).
- Aquifer exemption required for injection of produced water into Fort Union Formation at Shoshone-Arapahoe 16-34 located 3.5 mi northwest of Pavillion Field (EPA 2013).

Attainment of USDW Criteria– TDS and Major Ion Concentrations in Wind River Formation

Parameter	Daddow (1996) Median (Range)		Plafcan et al. (1995) Median (Range)		Pavillion Area (EPA Data) Median (Range)	
TDS	**490**	(211-5110)	**1030**	(248-5100)	**925**	(302-4921)
Ca	**10**	(1-486)	**45**	(1.7-380)	**51**	(3.3-452)
Mg	**2.2**	(0.1-195)	**8.2**	(0.095-99)	**5.3**	(0.02-147)
Na	**150**	(5-1500)	**285**	(4.5-1500)	**260**	(42-1290)
K			**2.45**	(0.1-30)	**2.45**	(0.18-10.5)
SO4	**201**	(2-3250)	**510**	(12-3300)	**551**	(90-3640)
Cl	**14**	(2-466)	**20**	(3-420)	**21**	(2.6-78)
F	**0.7**	(0.1-8.8)	**0.9**	(0.2-4.9)	**0.9**	(0.2-4.1)

Major ion chemistry in domestic wells in Pavillion Field is typical of the Wind River Formation (elevated TDS and SO4)

Secondary Standards
TDS = 500 mg/L
SO4 = 250 mg/L

Attainment of USDW Criteria

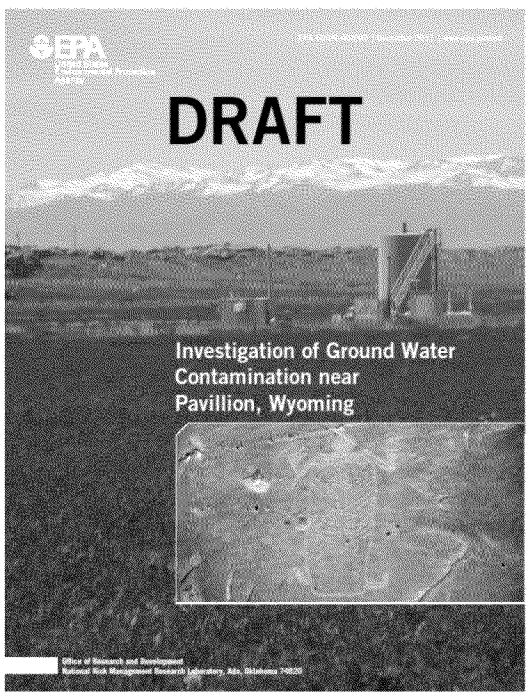
- *"The Wind River formation is considered both an aquifer and a USDW."*
- *"The Fort Union formation would also meet the definition of an aquifer and USDW as it contains fewer than 10,000 milligrams per liter (mg/l) of Total Dissolved Solids (TDS) and can provide sufficient quantity of groundwater to supply a public system."*

Pavillion Gas Well Integrity Evaluation

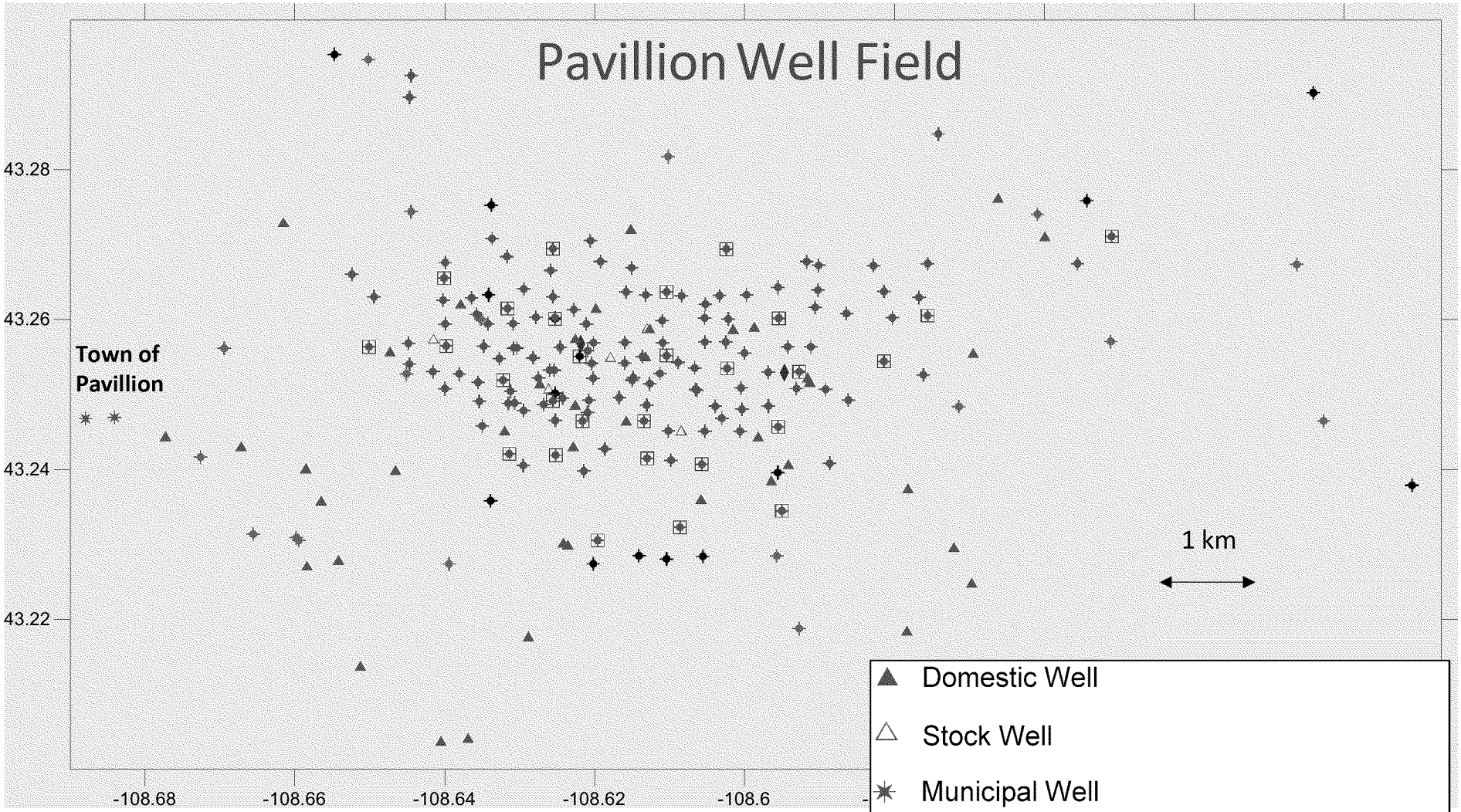
U.S. Environmental Protection Agency Region 8

July 25, 2013

"The Wind River Formation meets the definition of an Underground Source of Drinking Water (USDW) under the United Code of Federal Regulations, Title 40, Section 144.3."



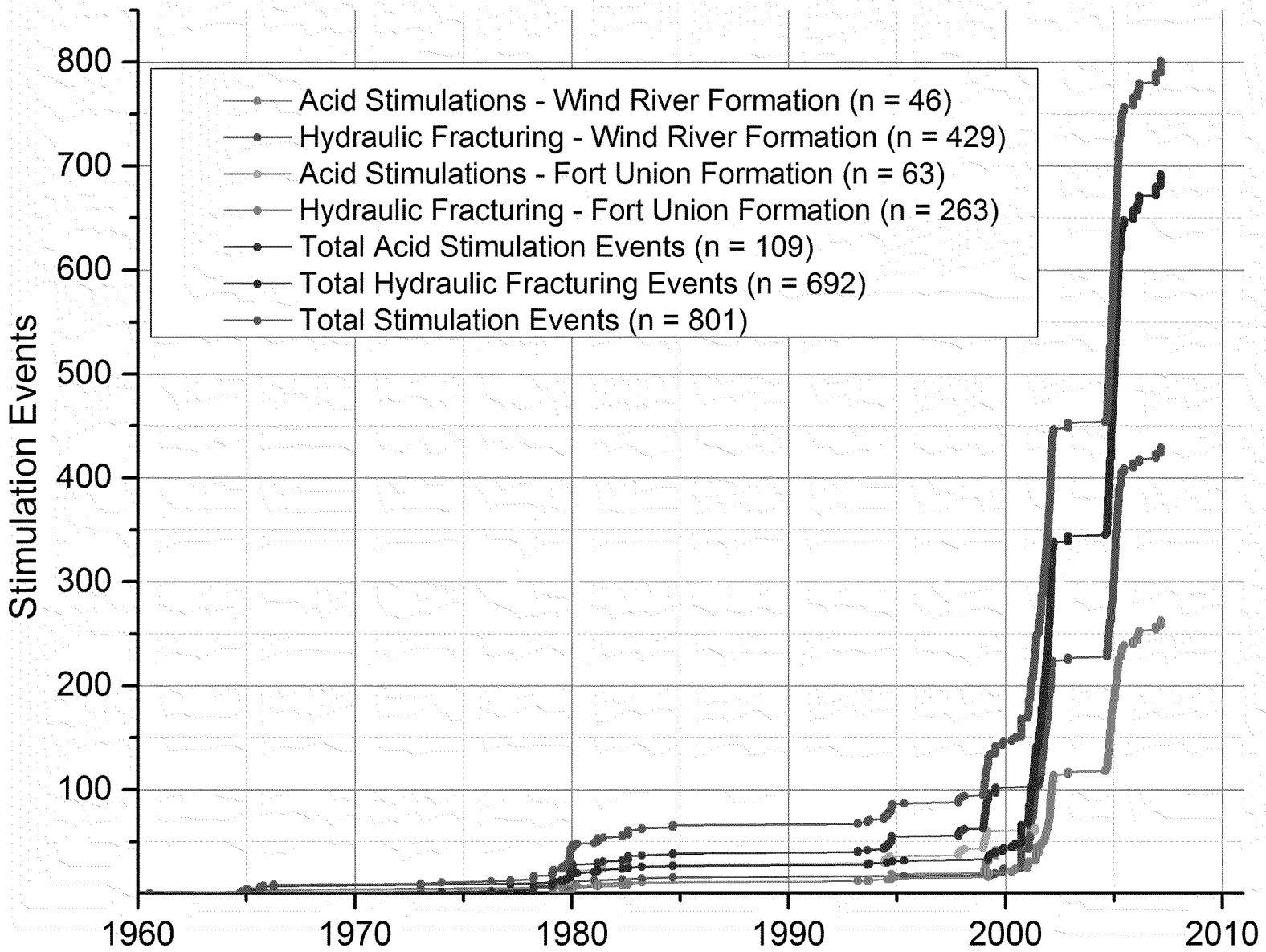
DiGiulio et al. 2011



Source: WOGCC (2014)

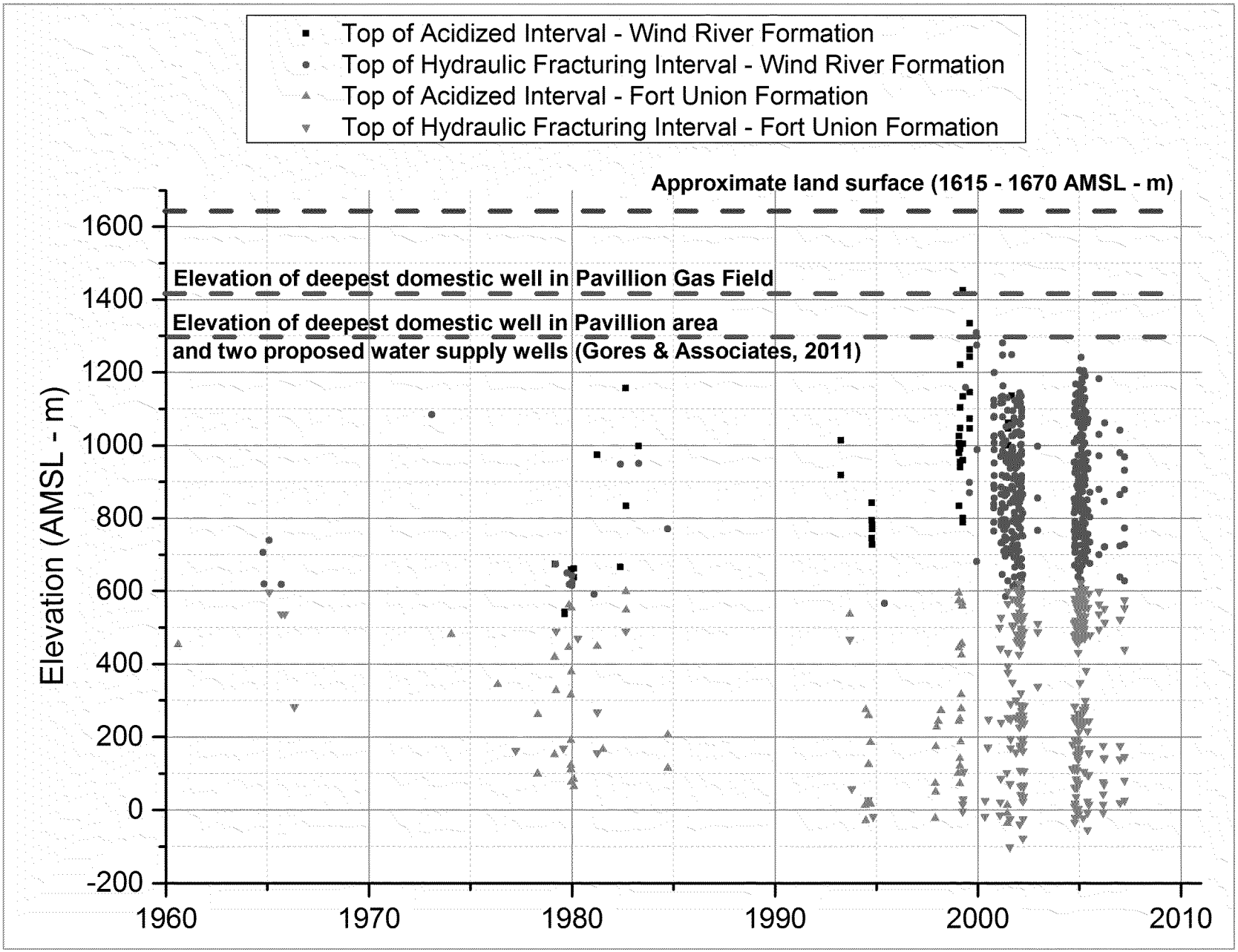
139 stimulated production wells, 15 stimulated P&A wells, 18 non-stimulated P&A wells, 28 pit locations

Documented StimulationEvents as a Function of Time



Source: WOGCC (2014)

Stimulation Elevations



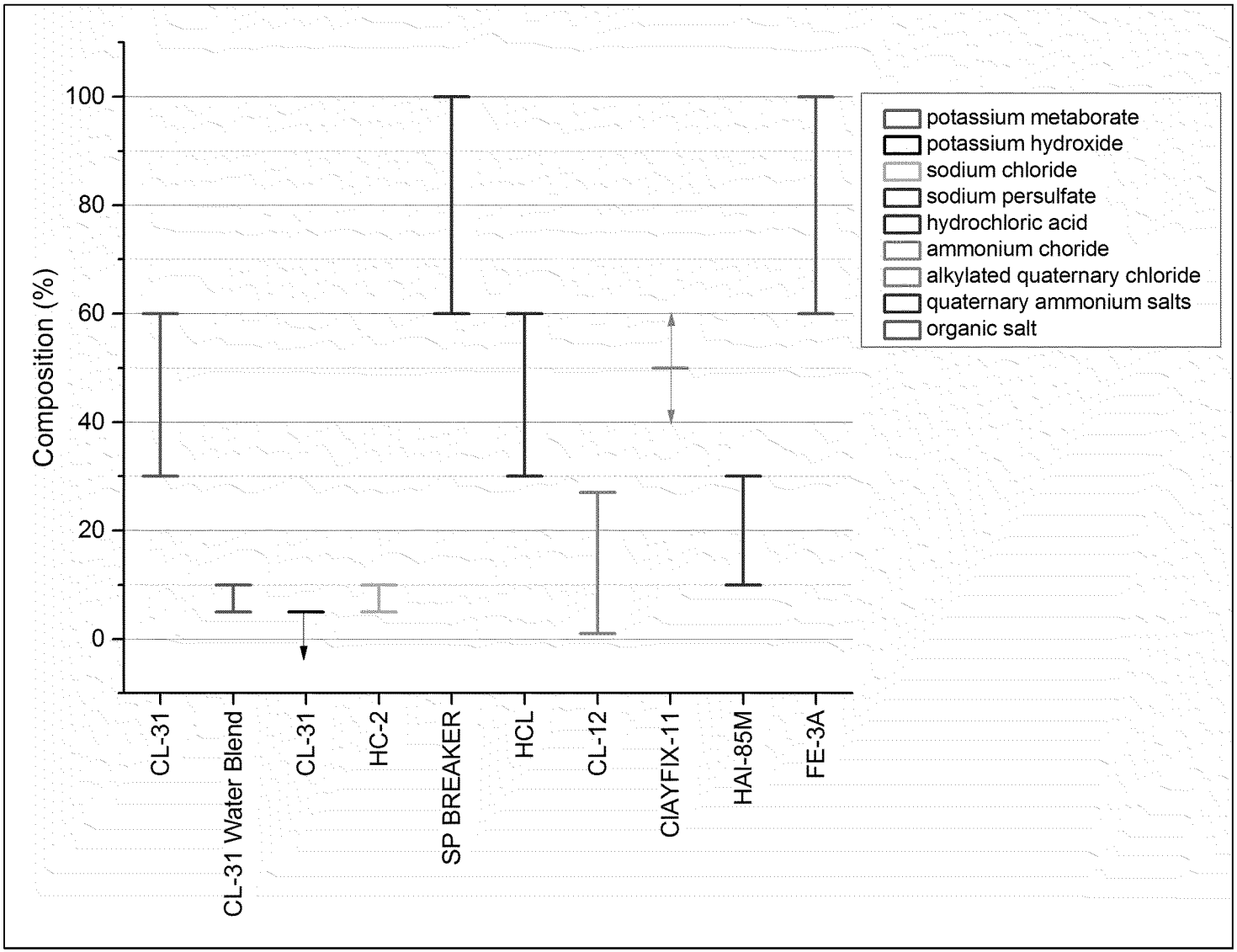
Source: WOGCC (2014)

Common Descriptions of Fluids in Well Completion Reports

- diesel fuel (undiluted)
- 6% KCl solution
- CO_2 foam (some N_2) with additives
- slickwater
- 15% HCl with Musol solvent and other “additives”
- 10% methanol solution with “additives”
- “gel”
- “linear gel”
- “x-link gel”
- “salt water”
- “clear frac”
- “fluid”
- “clean fluid”
- Numerous undefined fluids (e.g., “YF125 PSD frac fluid”, “P-12 solvent”, “WF 130”, “WF 135”)
- [blank or nothing]

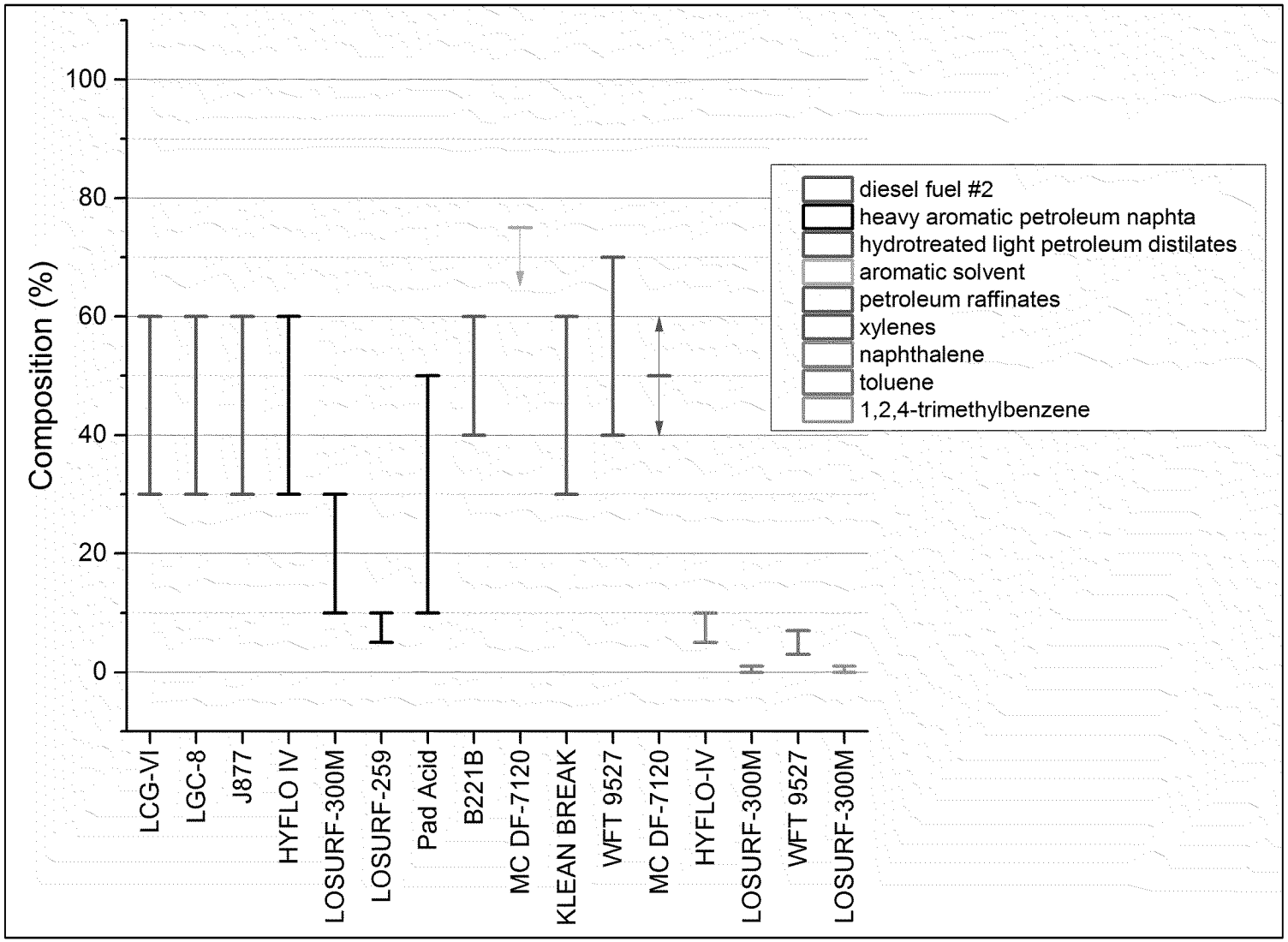
Source: WOGCC (2014)

Information from Material Safety Data Sheets (MSDSs) – Major Ions



Source: EPA (2010)

Information from Material Safety Data Sheets (MSDSs)– Diesel Range Organics and Aromatic Hydrocarbons

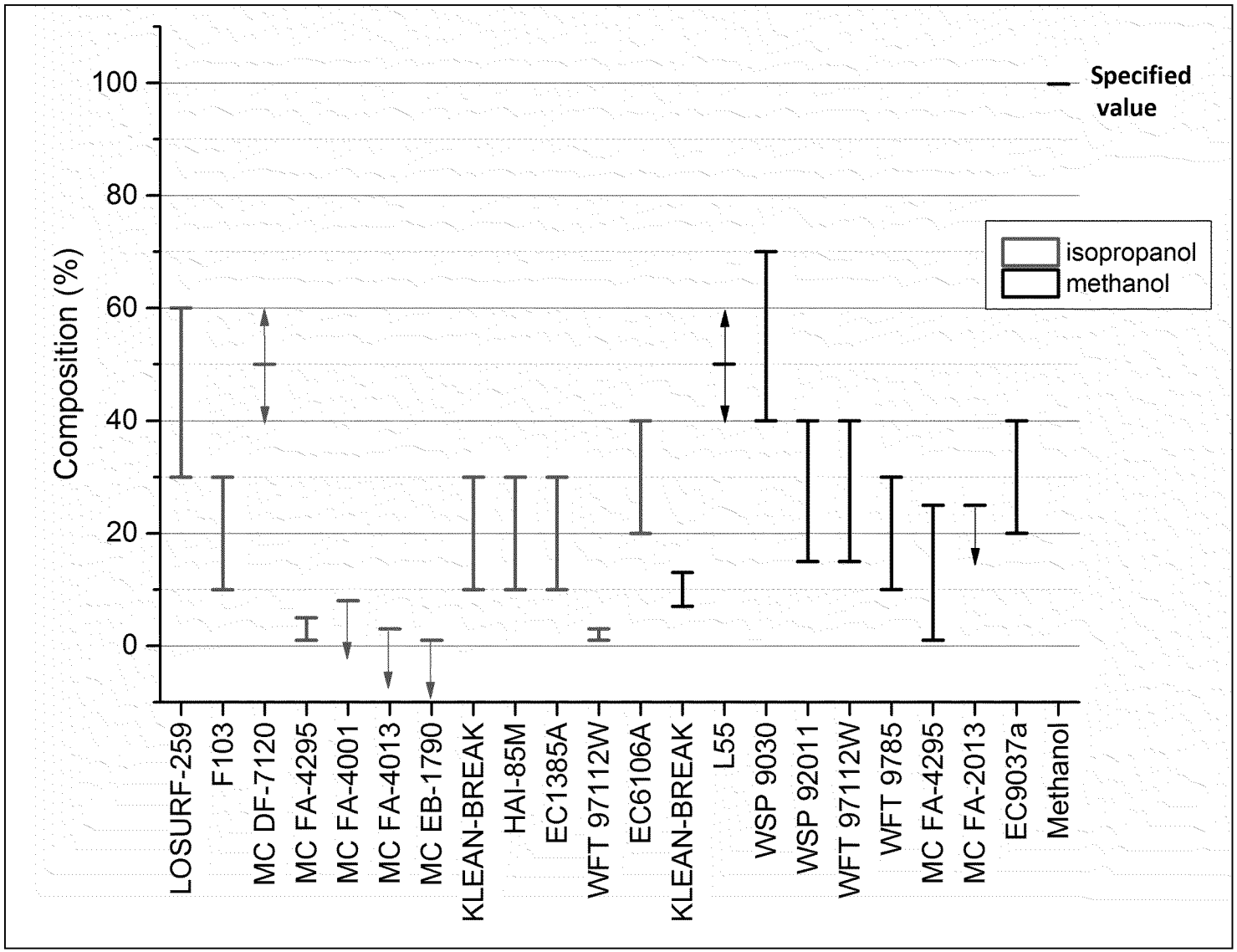


Less than specified value

No specified value

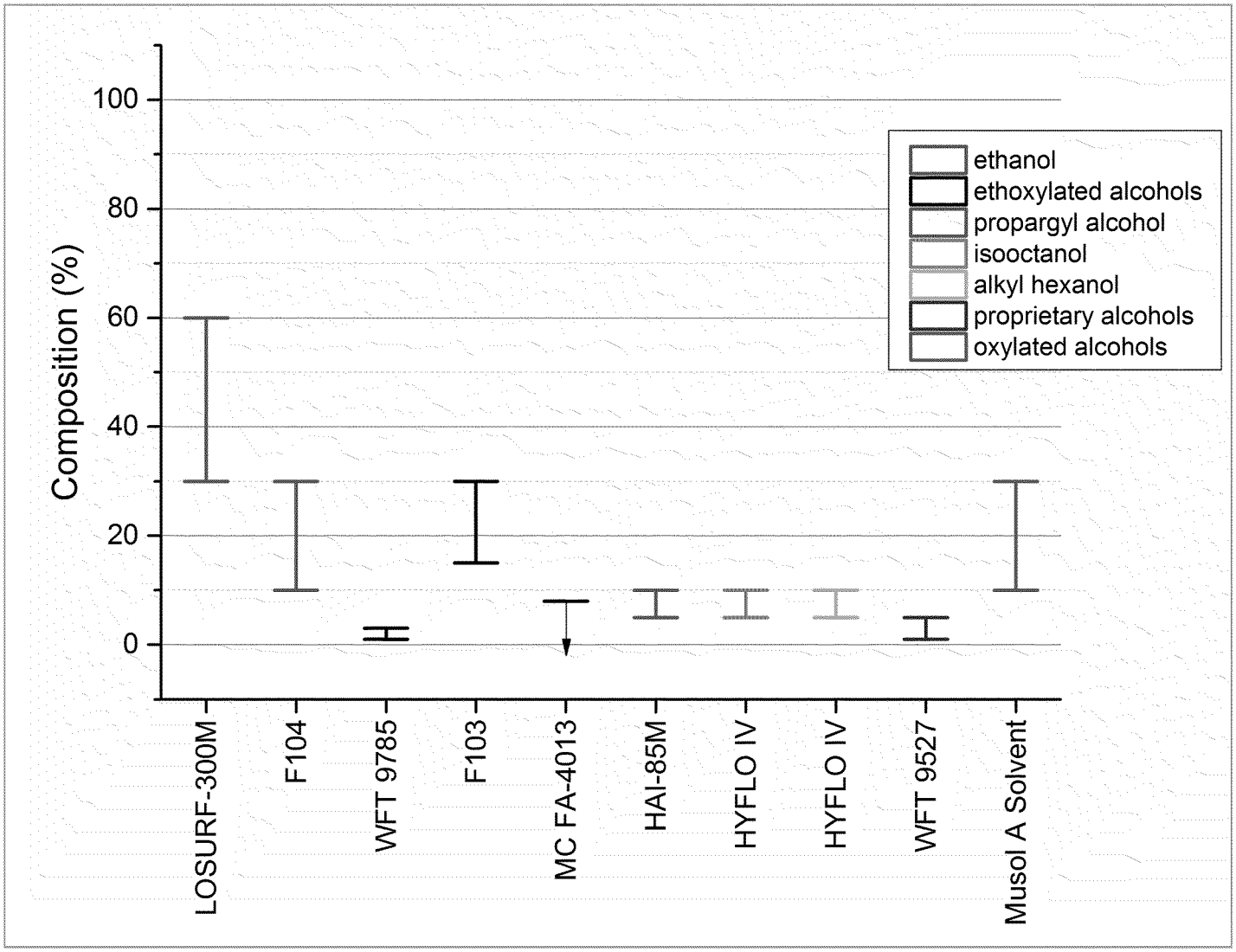
Source: EPA (2010)

Information from Material Safety Data Sheets (MSDSs) – Isopropanol and Methanol



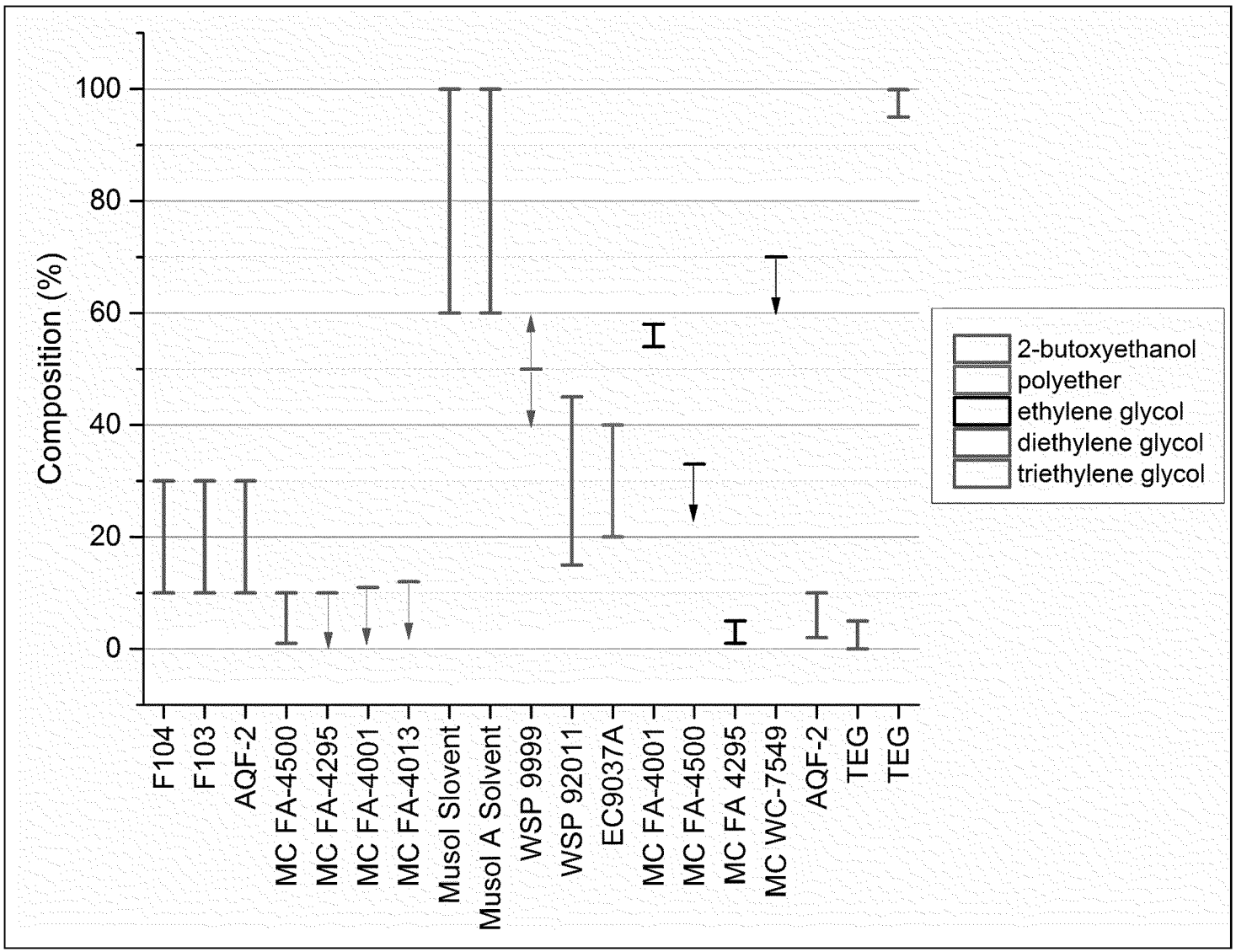
Source: EPA (2010)

Information from Material Safety Data Sheets (MSDSs)– Other Alcohols



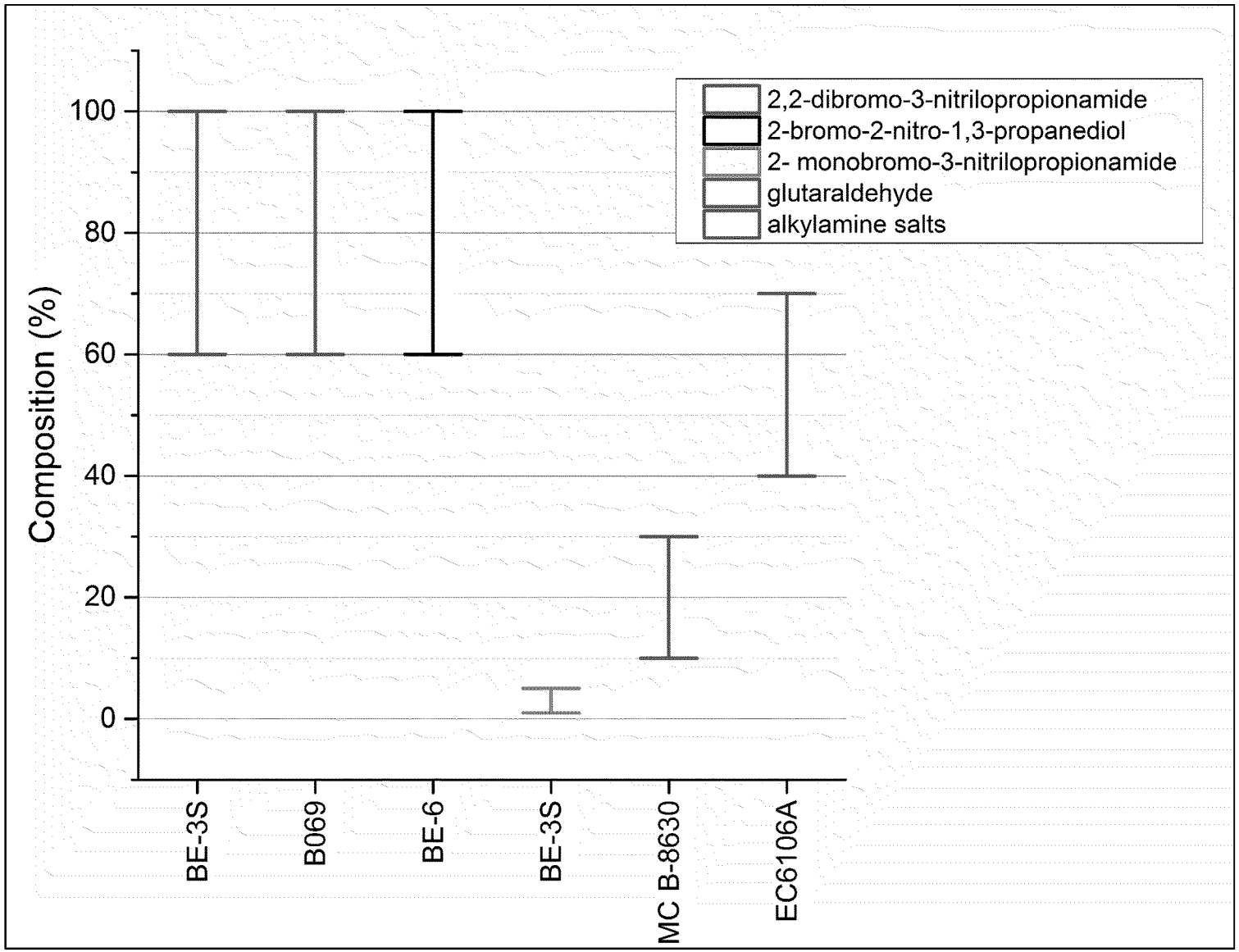
Source: EPA (2010)

Information from Material Safety Data Sheets (MSDSs) Glycols and Glycol Ethers



Source: EPA (2010)

Information from Material Safety Data Sheets (MSDSs) Biocides



Source: EPA (2010)

Conclusions and ResearchQuestions

Conclusions

The Wind River and Fort Union Formations in the Pavillion Field meet criteria as Underground Sources of Drinking Water (USDWs).

Thousands of gallons of undiluted diesel fuel and millions of gallons of fluids containing numerous inorganic and organic additives were injected directly into these USDWs during hundreds of stimulation events.

First documented injection of stimulation fluids into USDWs in a tight gas play.

Research Questions

Has impact occurred in these formations?

Have stimulation fluids been injected directly into USDWs in other tight gas plays?

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